Spherical Glass Based Fiber Optic Fabry-Perot Interferometric Probe for Refractive Index Sensing

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Abstract: A novel Fabry-Perot sensor, comprised a glass sphere bonded to a capillary and single-mode fiber, is proposed for refractive index sensing. It is characterized in air, water, ethanol, isopropanol, and glycerol. © 2020 The Author(s)

1. Introduction

Refractive index (RI) is an important physical quantity, which is measured in various production, diagnostic and quality monitoring processes [1–4]. Optical fiber sensors have proven to be reliable and robust sensing devices with characteristics such as immunity to electromagnetic interference, compact size, biocompatibility and real time measurement ability, making them suitable for demanding biomedical, chemical and industrial applications [5]. Various RI optical fiber sensors have been proposed in literature such as Fabry Perot interferometer (FPI) sensors [2], evanescent wave sensors [3], etched fiber Bragg grating sensors [6], micro-structured fiber Bragg grating refractive index sensors [7], and whispering gallery mode (WGM) resonators [8], etc. However, the challenge is to improve the simplicity of fabrication process and to introduce the cost effectiveness of the sensor.

Recently, Viphavakit et al. [2] reported a gold-coated Fabry-Perot interferometer for the measurement of oxygen concentration in terms of the change in refractive index of the red blood cells. In Viphavakit's work, a multimode silica fiber is integrated with single mode fiber and silica capillary (SMF-CAP) configuration. However, fabrication involves the sputtering of titanium and gold which is an expensive processing step. The literature also on the use of a spherical glass structure in combination with an optical fiber based FPI, for refractive index sensing [9,10], while the spherical glass structure has also been used previously for RI sensing using the WGM effect [8]. However, such sensors also exhibit challenges in fabrication. Herein we report on a simple spherical glass bead bonded to the SMF-CAP configuration. The simple and robust sensor design using a single mode glass optical fiber, a glass capillary and a glass bead with no coatings applied. Novelty of this sensor lies in its simple construction and simple fabrication process, which helps to ensures cost effective reproducibility sensor design with a high sensitivity. The proposed sensor may be used in biomedical and chemical processing applications for concentration and refractive index sensing.

2. Fabrication of Sensor, Experimental Results and Discussion

Fabrication of the sensor starts with the preparation of the SMF-CAP configuration and thereafter, the bonding of spherical glass bead to the capillary end using cyanoacrylate (CA) adhesive. The single mode fiber (SMF) used is bend insensitive (Corning® ClearCurve® ZBL Optical Bare Fiber) with cladding diameter as 125.0 ± 0.7 μm and mode field diameter as 9.65 ± 0.5 μm. The silica glass capillary (CAP) has internal and outer diameters of 132 μm and 220 μm respectively, have been used for the proposed sensor. The SMF is fused inside the CAP and then the distance between the end face of the fiber and end of the capillary is adjusted by polishing, following same procedure described in [2].

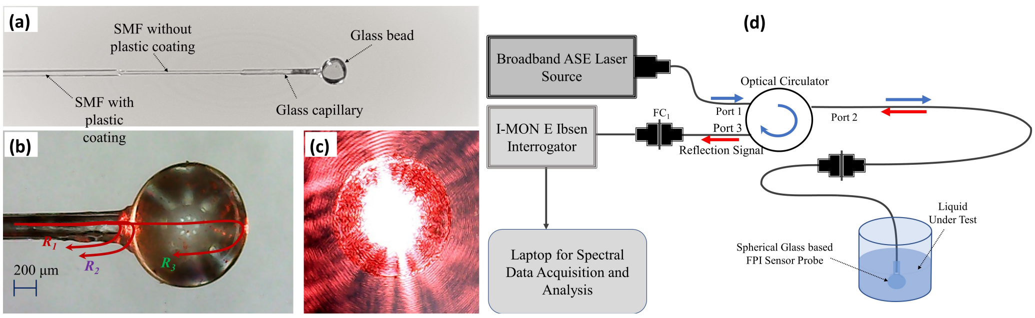

Fig. 1. (a) optical image of spherical glass based FPI probe sensor, (b) and (c) show the enlarged transverse image and top view of sensor, respectively with red laser excitation to visualize the reflection and resonance modes of spherical cavity. R_1, R_2 and R_3 show the reflections from SMF-Air, Air-Adhesive-Glass Bead, Glass bead-Air interfaces, respectively, (d) Experimental Setup for characterization.

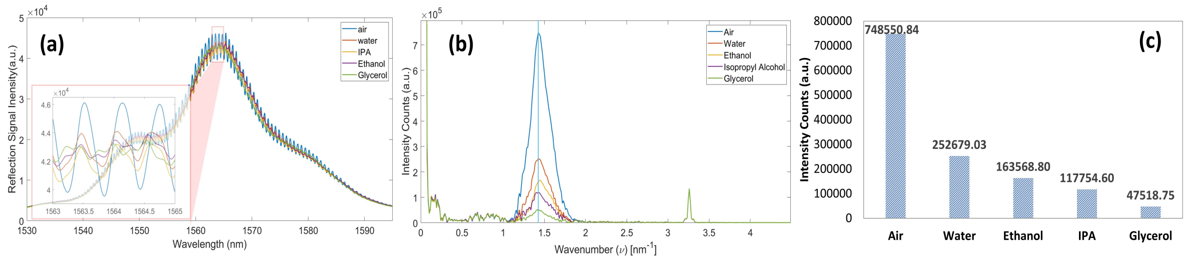

Fig. 2. Experimental results (a) Reflection spectra of proposed sensor for different RI media whereas the inset image are zoomed in spectra (b) FFT of acquired spectra (c) intensity counts from FFT of spectra at $\upsilon = 1.4254$
1

After polishing, the sensor subassembly is carefully dipped in cyanoacrylate adhesive and bonded to the spherical silica glass bead (diameter is ~1100 µm). Thereafter, the sensor is cured at room temperature for 2 hours. An image of the fabricated sensor is shown in Fig. 1(a). Figs. 1 (b) and 1 (c) provide images of the transverse and top view of the sensor when it is excited with a red laser light source. An FPI is formed by the air cavity between the SMF and glass sphere, producing reflections R1, and R2, while a further reflection R3 is created by the spherical glass bead shown in Fig. 1 (b). The experimental setup for the fabricated sensor is shown in Fig. 1 (d), which includes a broadband ASE laser source with a Gaussian shape spectrum centered at 1554.2 nm. The optical interrogator acquires 512 data points between 1527 nm and 1596 nm.

The sensor was characterized, at 25 °C for standard RI media: air, distilled water, ethanol, isopropyl alcohol (IPA) and glycerol, with refractive index values: 1.0003, 1.3164, 1.3661, 1.3520, 1.4571 RIU, respectively [11]. As the spectral resolution of the optical interrogator is just 512 points, a Fast Fourier Transform (FFT) of the spectral response is low quality due to low spectral resolution. The number of datapoints was increased without changes to the spectrum shape by using the digital signal processing technique of up-sampling. The spectra used in the date reported here was up-sampled seven times, see Fig. 2 (a). As shown in Fig. 2 (a), in the enlarged image of the spectra, that the spectrum amplitude responds to changes in the refractive index of the medium. The FFTs of the spectra have been calculated and plotted as shown in Fig. 2 (b), which show the wavenumber and corresponding amplitude in terms of intensity counts. It is evident from the FFTs that the intensity at $\upsilon = 1.4254\ nm^{-1}$, is decreased when the refractive index of the medium is increased, see Fig. 2 (b). The corresponding reflection signal intensity counts of the sensor are shown in Fig. 2 (c) for air, distilled water, ethanol, isopropyl alcohol, glycerol which are 748550.84, 252679.03, 163568.80, 117754.60, 47518.75 (a.u.), respectively. The sensor is very stable, reproducible and sensitive to changes in refractive index. Future work is proposed to enhance the extinction ratio of the reflection spectrum and to investigate the effects of temperature. The proposed sensor has potential applications in biomedical sensing and chemical processing for concentration and refractive index sensing.

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3. References

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